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13. ABSTRACT (Maximum 200 words) The objective of this project is to study MBE growth of PbSrSe with different Sr composition and the potential for detector applications. The PbSrSe material system ranges from UV wide bandgap semiconductor SrSe (3.8e eV) to mid-IR narrow gap semiconductor PbSe (0.26 eV). Therefore it is a very interesting material system to study. During this project, MBE-grown PbSrSe epitaxial layers with Sr composition ranging from 1 to 0 have been successfully demonstrated on Si and BaF ₂ substrate. The bandgap energies as well as the refractive indices were determined by optical transmission measurement. A distinct bandgap inversion from the direct to the indirect transition is observed for the first time at x ~ 0.20 as the Sr composition increases. <i>In situ</i> reflection high energy electron diffraction (RHEED), x-ray diffraction, and optical transmission are used to characterize the epi-layers and show that the material quality is reasonably high. However, doping especially p-type doping for wide gap SrSe is difficult. There is no doping problem for narrow gap small Sr composition PbSrSe materials. A new concept of growing PbSe-based quantum well materials on [110] orientation was also proposed. Preliminary MBE growth was successful. Future work will be focused on new detector structures on [110] orientation.			
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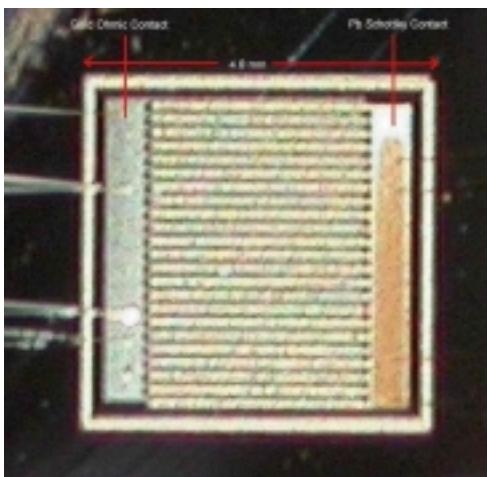
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SrSe UV Solar-Blind Photovoltaic Detector on Si

Army Research Office Program (DAAD19-00-1-0171)

PI: Zhisheng Shi, ECE, University of Oklahoma



Approach

- ◆ MBE growth of thin-film PbSrSe on BaF₂ and Si substrates
- ◆ Determine basic material parameters
- ◆ Develop processing technologies

New Objectives of the Project

Investigation of Pb_{1-x}Sr_xSe in the whole spectra range (x= 0-1). Determine the optical parameters and fabrication of detectors.

Highlights of Current Findings

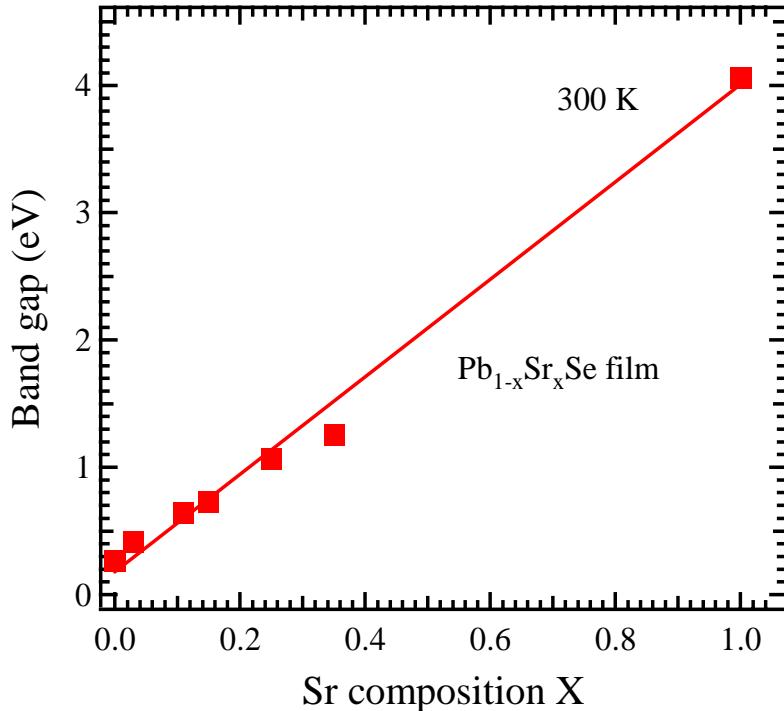
- ◆ Monocrystalline Pb_{1-x}Sr_xSe film growth in the whole spectra range (x=0-1)
- ◆ Temperature Dependent E_g, absorption coefficients and refractive indices determined for the first time
- ◆ Direct to indirect band transition observed for the first time.





Applications PbSrSe Material

- UV – Mid-IR detector
- RF/Microwave/Millimeter-wave Technology



Advantages of $\text{Pb}_{1-x}\text{Sr}_x\text{Se}$

- Huge wavelength coverage
 - multi-wavelength detection
- Good material quality on Si
 - integration with Si readout
- Low temperature growth
 - ROIC could withstand



Some Related Material Parameters

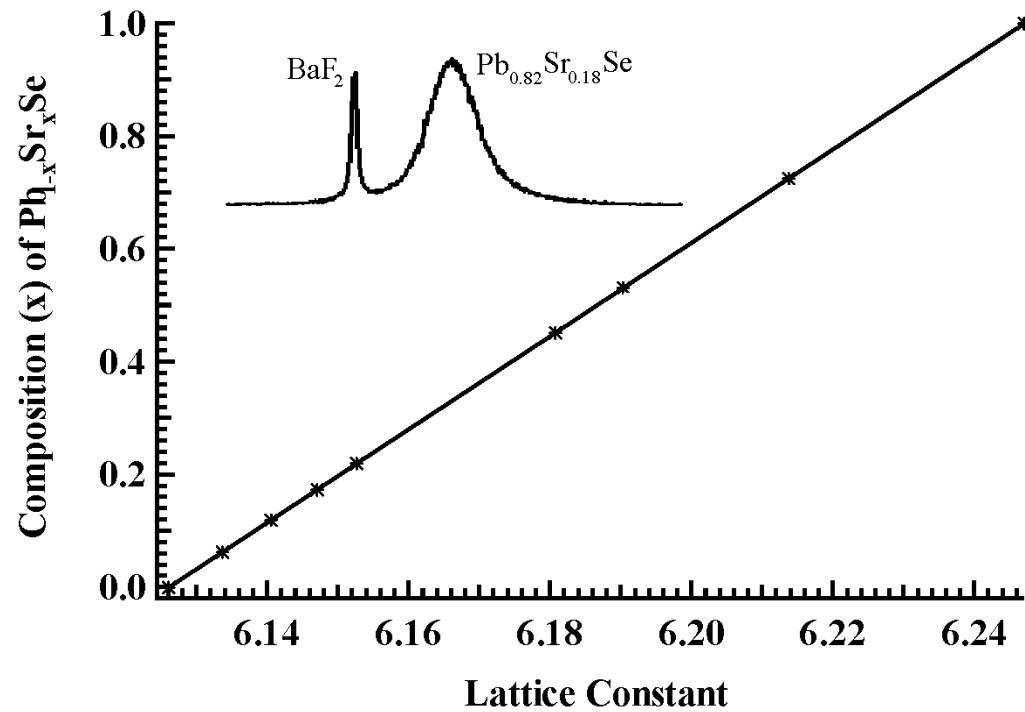
Materials	Crystal structure	Melting Point (°C)	Lattice constant (Å)	α (10-6 K-1)	Bandgap Energy (eV)
SrSe	Cubic (NaCl)	1600	6.22*	NA	3.94* (indirect) 4.18* (direct)
PbSe	Cubic (NaCl)		6.124*	19.4	0.265*
SrS	Cubic	2226	6.02	NA	4.7
Si	Diamond		5.43095	2.6	1.124
CaF ₂	Cubic (CaF ₂)		5.464	19.2	12.1
BaF ₂	Cubic (CaF ₂)		6.20	19.8	10.4

* Data determined in our Lab

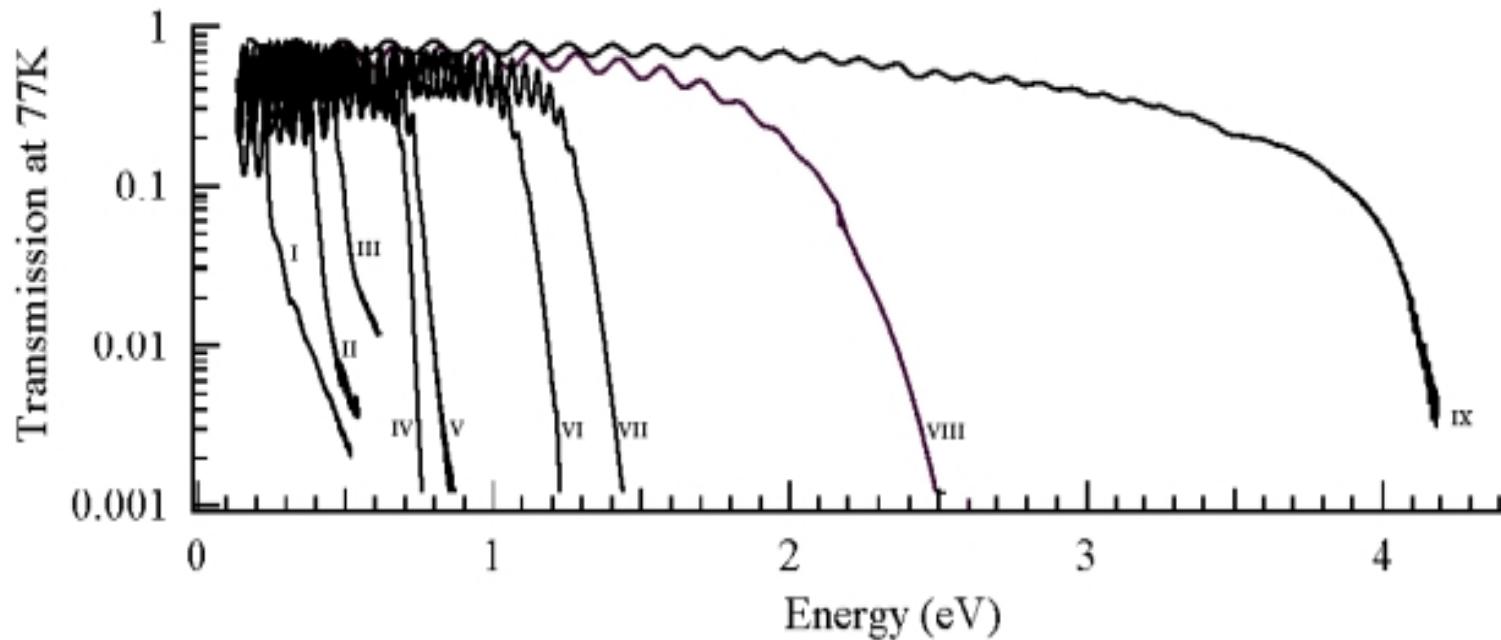
CaF₂ is nearly lattice matched to Si and thermal expansion matched to PbSe - an ideal buffer layer between Si and epi-layer to reduce dislocation and avoid cracking



Composition vs. lattice constant for $Pb_{1-x}Sr_xSe$ determined by X-ray



Direct to Indirect Band gap Transition

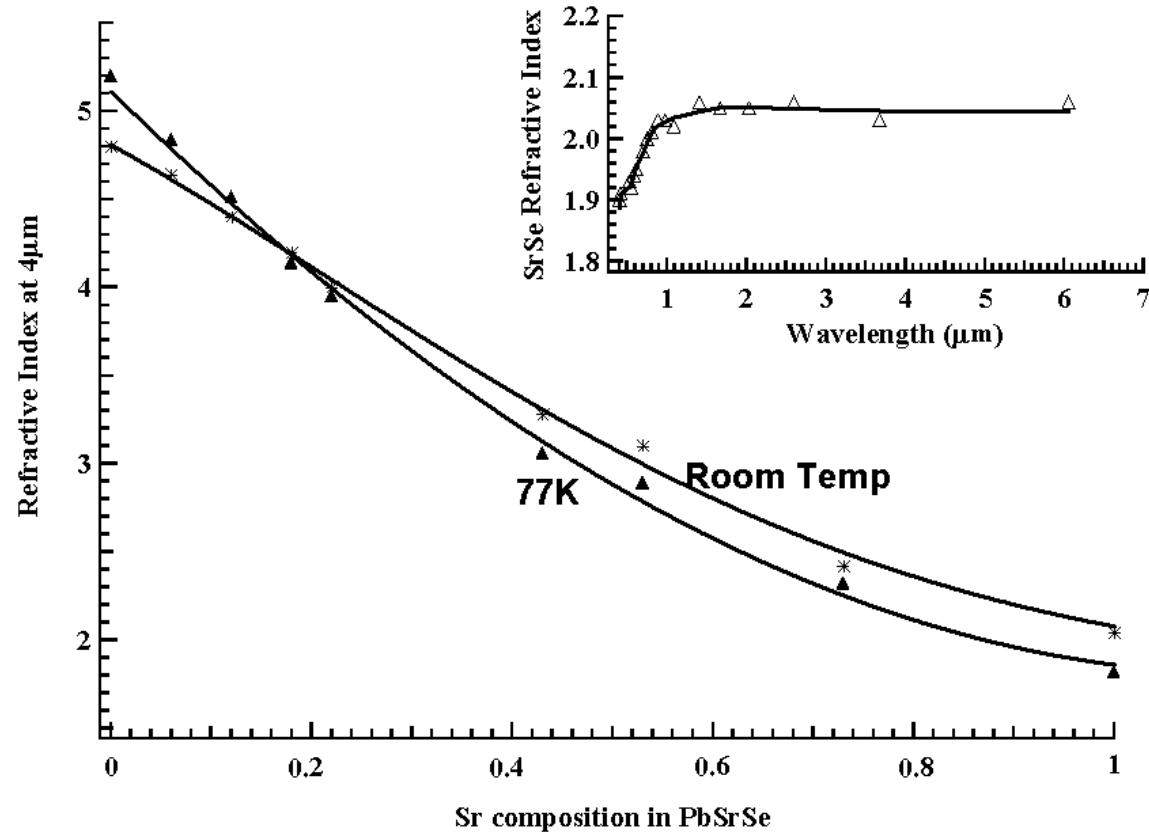


Transmission curves for $\text{Pb}_{1-x}\text{Sr}_x\text{Se}$ at 77K plotted in logarithmic scale. (I): PbSe , (II): $\text{Pb}_{0.94}\text{Sr}_{0.06}\text{Se}$, (III): $\text{Pb}_{0.88}\text{Sr}_{0.12}\text{Se}$, (IV): $\text{Pb}_{0.72}\text{Sr}_{0.18}\text{Se}$, (V): $\text{Pb}_{0.78}\text{Sr}_{0.22}\text{Se}$, (VI): $\text{Pb}_{0.57}\text{Sr}_{0.43}\text{Se}$, (VII): $\text{Pb}_{1-0.47}\text{Sr}_{0.53}\text{Se}$, (VIII): $\text{Pb}_{0.27}\text{Sr}_{0.73}\text{Se}$, (IX): SrSe .

Direct to Indirect band transition appears at $x \sim 0.2$

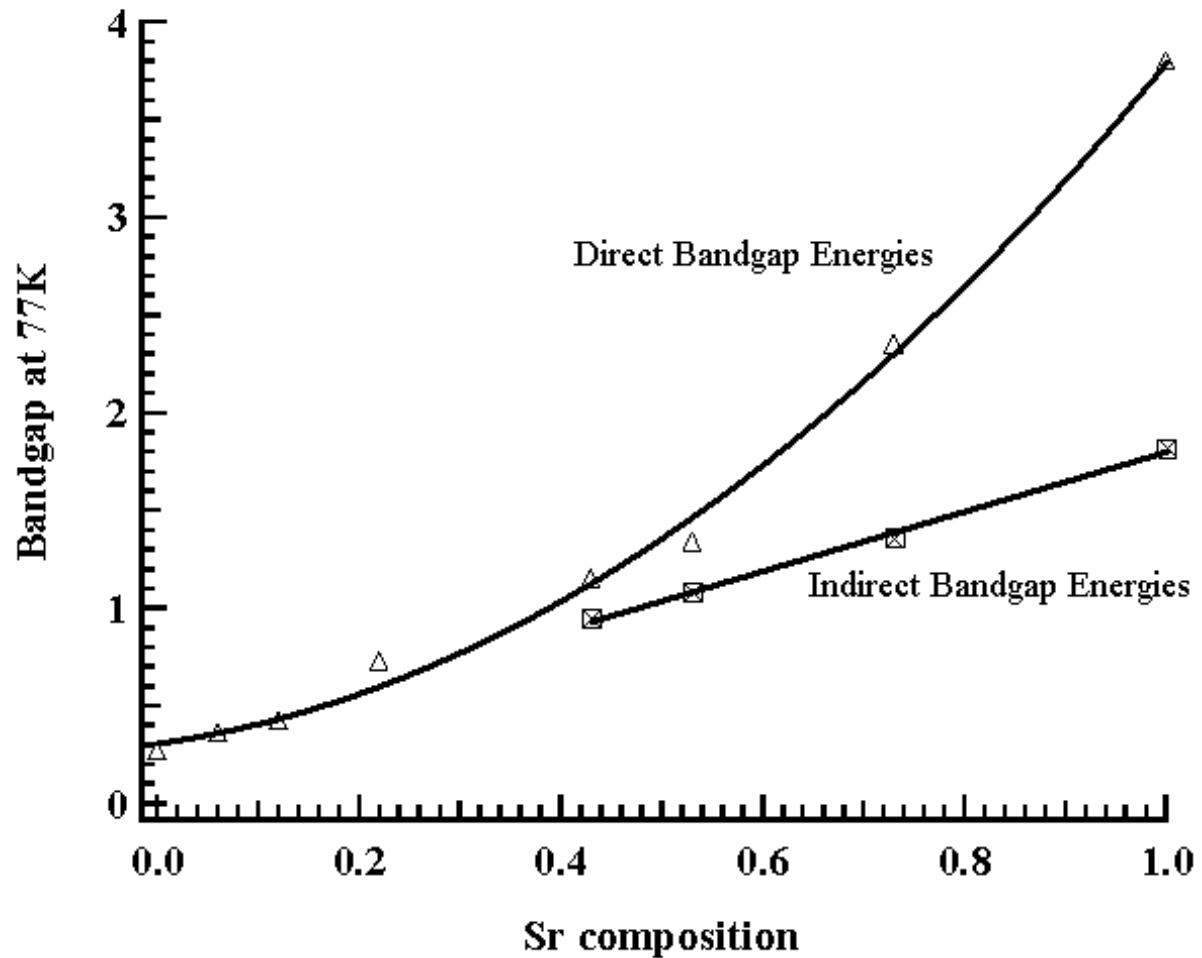


Refractive Indices



Refractive index of $\text{Pb}_{1-x}\text{Sr}_x\text{Se}$ for different compositions (x), at 77K and at room temperature.
Inset in the figure is the refractive index of SrSe at 77K

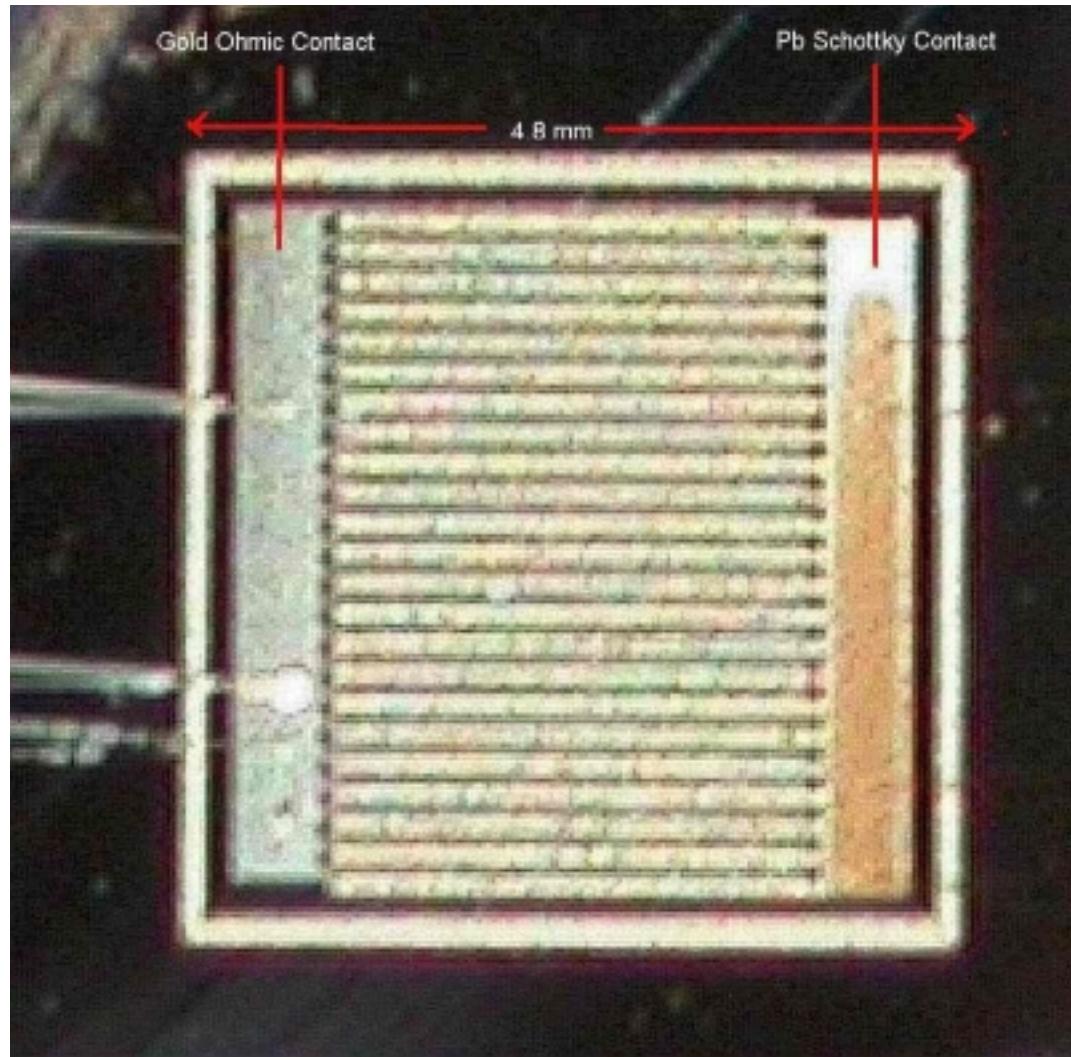
Bandgap Energies Of PbSrSe



Direct and Indirect bandgap energies of $\text{Pb}_{1-x}\text{Sr}_x\text{Se}$ at 77K for different compositions

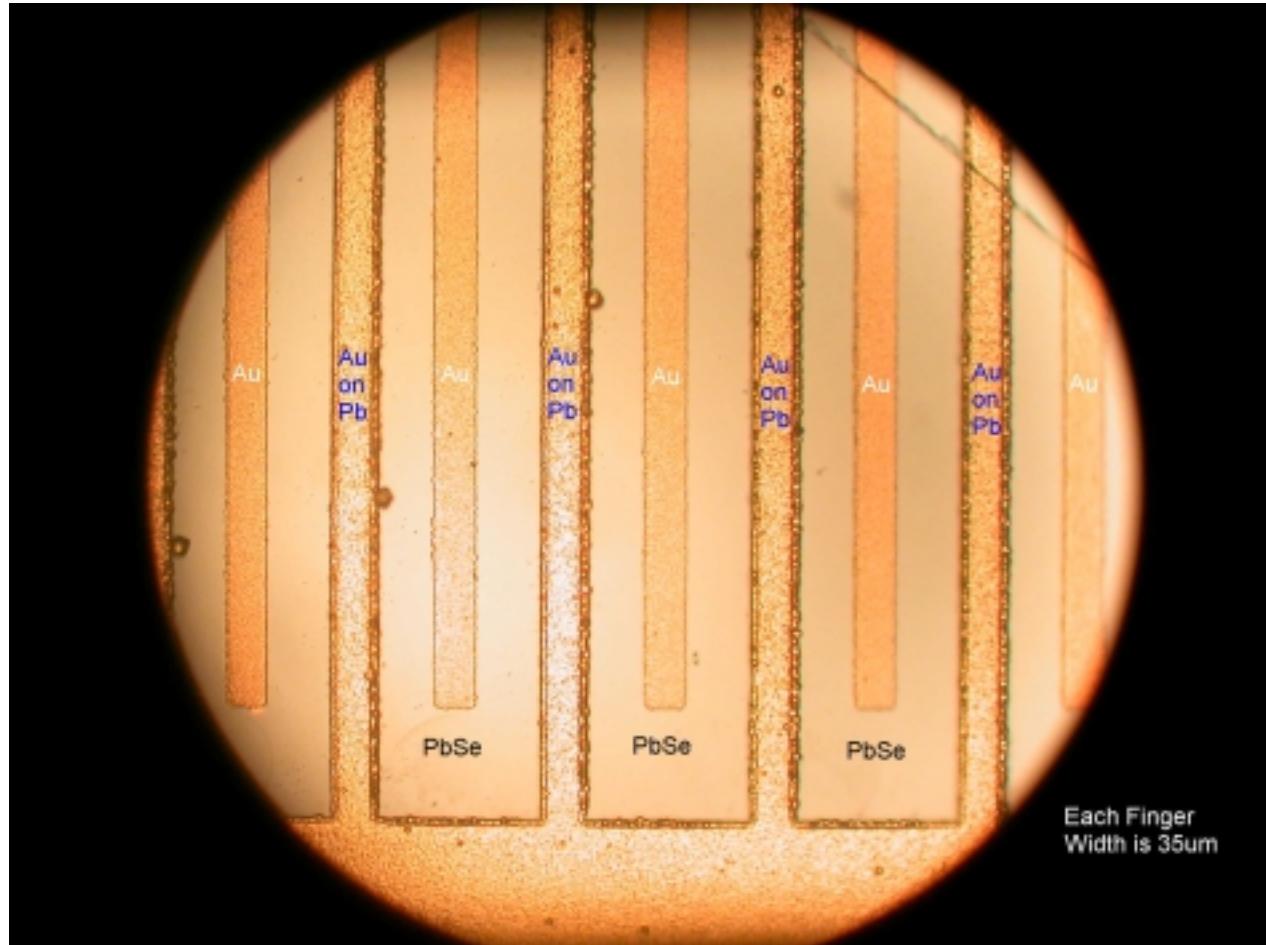


PbSe Schottky contact photovoltaic detector



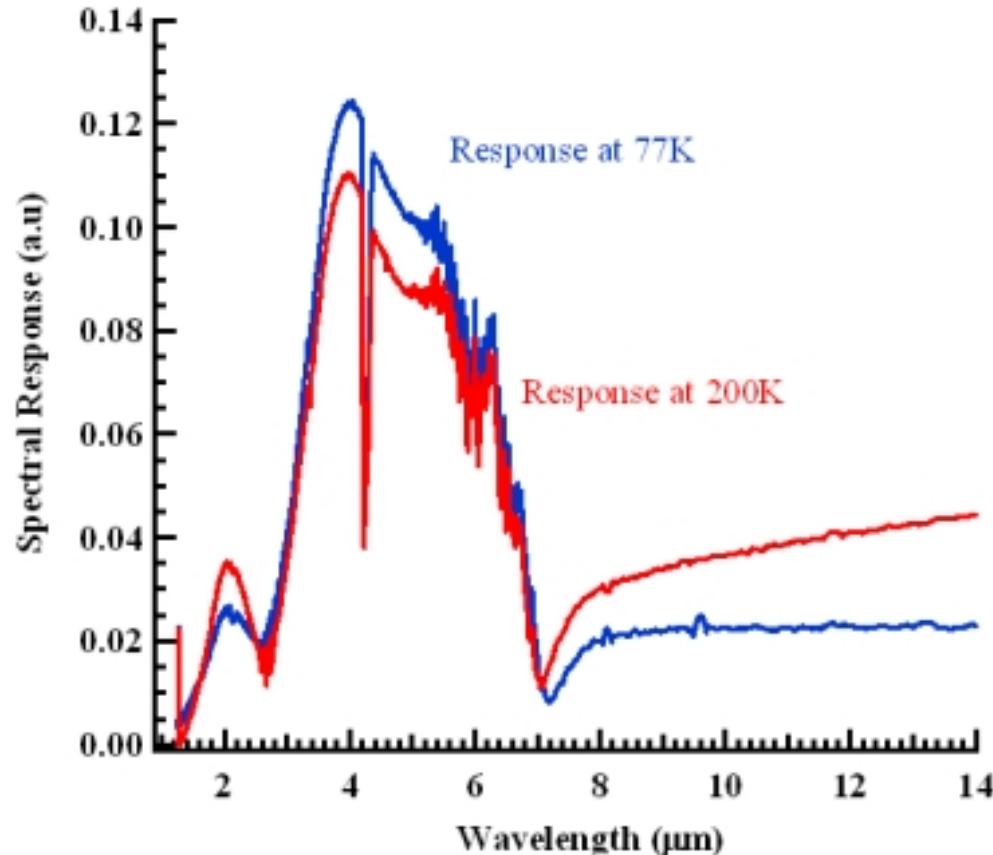


Au and Pb Finger contacts





Spectra response



Spectra response of PbSe detector at 77K and 200K. The center dip is due to CO_2 absorption.
The shoulder noises around 6 mm are caused by water absorption.



Future Work

Further Development of Detector Processing

- Passivation using BaF₂
- Reduction of background carrier concentration

P-N Junction Mid-IR Detector

Resonant Cavity Enhanced Mid-IR Detector

Detector Array On Si



Paper published

- 1) A. Majumdar, H. Z. Xu, F. Zhao, J. C. Keay, L. Jayasinghe, S. Khosravani, X. Lu, V. Kelkar, and Z. Shi, “Bandgap energies and refractive indices of $\text{Pb}_{1-x}\text{Sr}_x\text{Se}$ ”, *J. Appl. Phys.*, **95**, 939(2004)
- 2) F. Zhao, H. Wu, A. Majumdar and Z. Shi, “Continuous wave optically pumped lead-salt mid-infrared quantum-well vertical-cavity surface-emitting lasers”, *Appl. Phys. Lett.*, **83**, 5129 (2003).
- 3) A. Majumdar, H.Z. Xu, F. Zhao, L. Jayasinghe, S. Khosravani, X. Lu, V. Kelkar, Z. Shi, “Bandgap Energies and Refractive Indices of $\text{Pb}_{1-x}\text{Sr}_x\text{Se}$ ”, *MRS Proceedings*, Symposium I “Optoelectronics of Group-IV-Based Materials”, Editors: Tom Gregorkiewicz, Robert G. Elliman, Philippe M. Fauchet, James A. Hutchby, Volume 770, I7.9.



Graduate Students Supported

- 1) Mr. Shahriar Khosravani (Ph.D candidate, graduated in 2003)
- 2) Mr. Tao Zheng, (Transferred to computer Science department)
- 3) Mr. Vishal Kelkar (MS candidate, graduated in 2003)
- 4) Swathi Bondili (MS candidate, expected to graduate in May 2005)
- 5) Shikha Jain (PhD candidate, started in August 2004)